The transverse energy per charged particle estimates in the framework of a statistical model

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The transverse energies and the charged particle multiplicities at midrapidity as well as their ratio, $dE_T/d\eta\ |_{mid}\ /dN_{ch}/d\eta|_{mid}$, are evaluated in a statistical model with expansion for the wide range of heavy-ion collisions, from AGS to RHIC at $\sqrt{s_{NN}} = 200$ GeV. Full description of decays of hadron resonances is applied in calculations of both $dE_T/d\eta|_{mid}$ and $dN_{ch}/d\eta|_{mid}$. The predictions of the model at the freeze-out parameters, established independently from observed particle yields and p_T spectra, agree well with the experimental data.

The statistical model has succeeded in the description of particle yield ratios and p_T spectra measured in heavy-ion collisions [1,2,3,4,5,6,7,8,9,10,11,12,13,14]. Transverse energy ($dE_T/d\eta$) and charged particle multiplicity densities ($dN_{ch}/d\eta$) are global observables whose measurements are independent of hadron spectroscopy, therefore they could be used as an additional test of the self-consistency of the statistical model.

The experimentally measured transverse energy is defined as

$$E_T = \sum_{i=1}^{L} \hat{E}_i \cdot \sin\theta_i \ , \tag{1}$$

where θ_i is the polar angle, $\hat{E}_i$ denotes $E_i - m_N$ (m_N means the nucleon mass) for baryons and the total energy E_i for all other particles, and the sum is taken over all L emitted particles [15]. Additionally, in the case of RHIC at $\sqrt{s_{NN}} = 200$ GeV, $E_i + m_N$ is taken instead of E_i for antibaryons [16].

The statistical model with single freeze-out [9,10,12] is applied for evaluations of $dE_T/d\eta$ and $dN_{ch}/d\eta$ at midrapidity. Details of this analysis can be found elsewhere [17,18]. The foundations of the model are as follows: (a) the chemical and thermal freeze-outs take place simultaneously, (b) all confirmed resonances up to a mass of 2 GeV from the Particle Data Tables [19] are taken into account, (c) a freeze-out hypersurface is defined by the equation $\tau = \sqrt{t^2 - r_x^2 - r_y^2 - r_z^2} = const$, ($d$) the four-velocity of an element of the freeze-out hypersurface is proportional to its coordinate, $u^\mu = x^\mu/\tau$, (e) the transverse

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Table 1
Values of $dE_T/d\eta|_{mid}$ and $dN_{ch}/d\eta|_{mid}$ calculated in the framework of the statistical model with expansion. In the first column thermal and geometric parameters are listed for the corresponding collisions. The data are for the most central collisions.

Collision case	$dE_T/d\eta\|_{mid}$ [GeV]		$dN_{ch}/d\eta\|_{mid}$	
	Theory	Experiment	Theory	Experiment
Au-Au at RHIC, $\sqrt{s_{NN}} = 200$ GeV: $T = 165.6$ MeV, $\mu_B = 28.5$ MeV, $\rho_{max} = 7.15$ fm, $\tau = 7.86$ fm [11]	$585^{(a)}$	597 ± 34 [16]	589	699 ± 46 [16] $579 \pm 29^{(b)}$ [25]
Au-Au at RHIC, $\sqrt{s_{NN}} = 130$ GeV: $T = 165$ MeV, $\mu_B = 41$ MeV, $\rho_{max} = 6.9$ fm, $\tau = 8.2$ fm [12]	507	503 ± 25 [15]	555	622 ± 41 [20] $568 \pm 47^{(b)}$ [21]
Pb-Pb at SPS: $T = 164$ MeV, $\mu_B = 234$ MeV, $\rho_{max} = 6.45$ fm, $\tau = 5.74$ fm [13,14]	447	363 ± 91 [22]	476	464^{+20}_{-13} [22]
Au-Au at AGS: $T = 130$ MeV, $\mu_B = 540$ MeV, $\beta_\perp^{max} = 0.675$, $\rho_{max} = 6.52$ fm [1,4]	224	≈ 200 [23]	271	≈ 270 [24]
Si-Pb at AGS: $T = 120$ MeV, $\mu_B = 540$ MeV, $\beta_\perp^{max} = 0.54$, $\rho_{max} = 5.02$ fm [1,4]	57	≈ 62 [24]	91	$\approx 115 - 120$ [24]

(a) For the modified definition of E_T, *i.e.* $E_i + m_N$ is taken instead of E_i for antibaryons, see eq. (1).
(b) For the charged particle multiplicity expressed as the sum of integrated charged hadron yields.

size is restricted by the condition $r = \sqrt{r_x^2 + r_y^2} < \rho_{max}$. The maximum transverse-flow parameter is expressed as $\beta_\perp^{max} = (\rho_{max}/\tau)/(\sqrt{1 + (\rho_{max}/\tau)^2})$. The model has four parameters, namely, the two thermal parameters, the temperature T and the baryon number chemical potential μ_B, and the two geometric parameters, τ and ρ_{max}. Values of these parameters were established from fits to particle yield ratios and p_T spectra (see the first column of table 1). The invariant distribution of the measured particles of species i has the Cooper-Frye form [9,10]. The distribution collects, besides the thermal one, also contributions from simple and sequential decays such that at least one of the final secondaries is of the i kind (for details, see [12,18]). Having integrated this distribution suitably over p_T and summing up over final particles, one can obtain $dE_T/d\eta$ and $dN_{ch}/d\eta$. The results together with the corresponding experimental data are listed in table 1.

Generally, the predictions agree well with the data. However, the 15% underestimation of the charged particle density has been found for RHIC. This can be explained by the existing inconsistency in measurements of the charged particle multiplicity at RHIC. Namely, the sum of integrated charged hadron yields is substantially below the directly measured $dN_{ch}/d\eta|_{mid}$ (see table 1). Note that values of this sum agree very well with the

Table 2
Values of the ratio $dE_T/d\eta|_{mid}/dN_{ch}/d\eta|_{mid}$ calculated in the framework of the statistical model with expansion. The data are for the most central collisions.

Collision case	$dE_T/d\eta\vert_{mid}/dN_{ch}/d\eta\vert_{mid}$ [GeV]	
	Theory	Experiment
Au-Au at RHIC at $\sqrt{s_{NN}} = 200$ GeV	0.99[(a)]	0.87 ± 0.06 [16]
		1.03 ± 0.08[(b)]
Au-Au at RHIC at $\sqrt{s_{NN}} = 130$ GeV	0.91	0.81 ± 0.06 [15]
		0.89 ± 0.09[(b)]
Pb-Pb at SPS	0.94	0.78 ± 0.21 [22]
Au-Au at AGS	0.83	0.72 ± 0.08 [24]
Si-Pb at AGS	0.63	0.52-0.54 [24]

(a) For the modified definition of E_T, *i.e.* $E_i + m_N$ is taken instead of E_i for antibaryons, see eq. (1).
(b) Author calculations with the use of experimental values given in table 1 and the denominator expressed as the sum of integrated charged hadron yields.

model predictions. Estimates of the ratio $dE_T/d\eta|_{mid}/dN_{ch}/d\eta|_{mid}$ are collected in table 2 together with the corresponding data. These results have been also depicted in fig. 1. The 15% overall overestimation has been obtained. In the RHIC case the mentioned underestimation of $dN_{ch}/d\eta|_{mid}$ is the reason for that. But if $dN_{ch}/d\eta|_{mid}$ from the summing up of integrated hadron yields is put in the denominator, the theoretical predictions agree very well with the data.

To conclude, the thermal model has been used to reproduce transverse energy and charged particle multiplicity pseudorapidity densities and their ratio from AGS, SPS and RHIC. The evaluations have been made at the thermal and geometric freeze-out parameters obtained in previous analyses of measured particle ratios and p_T spectra. The good accuracy of predictions has confirmed, in an alternative way, the applicability of the thermal model to the description of the soft part of the particle production in heavy-ion collisions.

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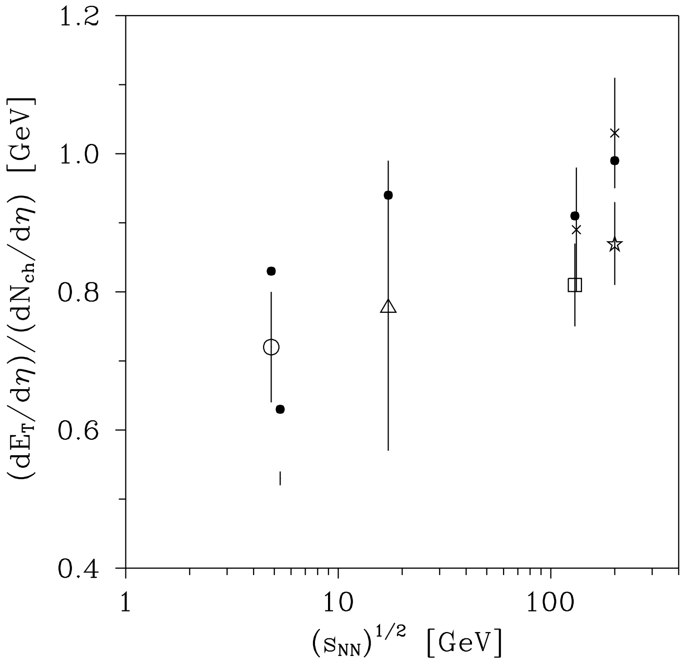

Figure 1. Values of the transverse energy per charged particle at midrapidity for the most central collisions. Black dots denote the model evaluations. Also data points for AGS [24] (a circle for Au-Au and a vertical bar for Si-Pb), SPS [22] (triangle), RHIC at $\sqrt{s_{NN}} = 130$ GeV [15] (square) and RHIC at $\sqrt{s_{NN}} = 200$ GeV [16] (star) are depicted. For RHIC, points with the sum of integrated charged hadron yields substituted for the denominator are also depicted (crosses).

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